Philosophically, how can one prove the existence of causality?

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In order to prove the existence of causality, it is necessary to use modern knowledge of physics. Let us recall that philosophy is a form of knowledge of the world, which is based on a system of knowledge about reality and man.

Our reality in the physical sense is the Universe, that is, our space-time. According to A. Einstein's STR, space and time can no longer be considered separately, since in reality there is a single 4-dimensional space-time continuum (x, y, z, t). It is this continuum that represents the place where all events take place in time and space, to which we attribute causal relationships. Therefore, it is impossible to understand the essence of causality in our Universe without taking into account the existence of a single 4-dimensional continuum.

"In 1907, Minkowski proposed a geometric representation of the kinematics of the theory of relativity, introducing a four-dimensional pseudo-Euclidean space (now known as Minkowski space).

In this model, time and space are not different entities, but are interconnected dimensions of a single space-time, and all relativistic effects have received a clear geometric interpretation.

Minkowski declared:

"From now on, time itself and space itself become an empty fiction, and only their unity preserves the chance for reality".

Minkowski's model significantly helped Einstein to develop the general theory of relativity, fully based on similar ideas" [1].

Note that philosophers and scientists of the past presented space as a place of events. Moreover, such a "Newtonian space" does not depend on time. Time was accepted as universal and unchanging. This is an absolutely erroneous idea about our reality, that is, about space and time.

Since, depending on the speed of movement of the observer, both space and time can change their characteristics: time can slow down, and space can be curved. As a consequence, such an incorrect model of "Newtonian space and time" leads to the fact that the existence of causality cannot be proved, and it is accepted as a fact. Considering Einstein's theory of relativity, causality in our world appears logically and inevitably. Here is a proof.

Causality in the physical and philosophical sense means that when one object (cause) acts, the corresponding expected change of another object (effect) occurs.

Event 1 (Cause) → Event 2 (Consequence).

Naturally, cause and effect occur in the real Universe and are separated by a certain time interval (Δt).

Our Universe is a 4-dimensional space-time continuum. Therefore, to describe events in the continuum, it is necessary to use the concept that most fully characterizes the given continuum. That is, you need to use the concept of “interval” (S), and not “length” and “time”. Since the length and time in different inertial systems may differ, and the interval will always be constant. At its core, the interval (S) is the “distance” between two events in real 4-dimensional spacetime.

The interval (S) in the inertial reference system, with Cartesian coordinates (x, y, z) and time (t), for an infinitely small displacement in space-time has the form:

$$dS^2 = c^2 * dt^2 – dx^2 – dy^2 – dz^2$$

or

$$dS^2 = c^2 * dt^2 – dL^2$$

where S - is the interval,

L - is the distance between two points, c - is the speed of light, t - is time.

For finite differences of coordinates, you can write:

$$S^2 = c^2 * \Delta t^2 – \Delta L^2$$

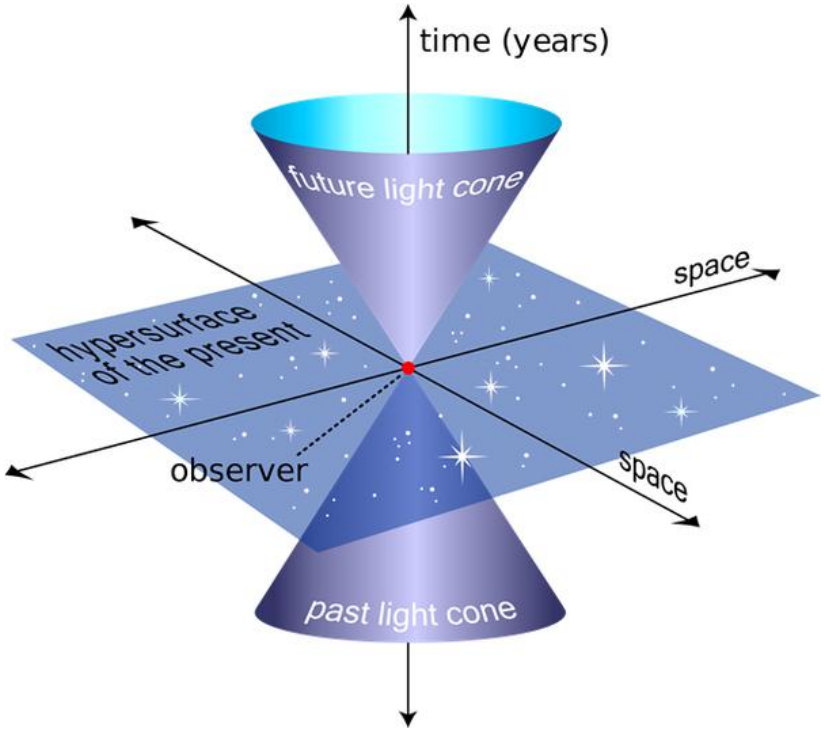
Since we are considering causal events (Cause → Effect), the interval should be timelike. That is, the square of the interval between both events must be greater than zero ($S^2 > 0$).

The essence of the timelike interval ($S^2 > 0$) is that there is such a frame of reference in which both events took place in the same place, but at different times (Δt). In fact, in this case, the frame of reference plays the role of a kind of “Newtonian space”.

It is important to note that for causally related events, any interaction between them always propagates at a speed no greater than the speed of light in a vacuum. Consequently, the very existence of causality between events is a consequence of the fact that the speed of light is the limiting speed of transmission of interactions in the Universe. And since the speed of light in a vacuum is a fundamental constant of the Universe, then causality between events is also a fundamental characteristic of our really existing Universe. That is, the Universe initially possesses causality, and causality is an integral characteristic of the Universe.

Therefore, causality in the Universe can be absent only if it is possible to overcome the speed of light in a vacuum. This is impossible in principle, therefore, in our Universe, all events will always be causally related.

The above is well demonstrated by such a concept as “light cone” [2].



If we consider an observer who is in the present time, then all causally related events form a light cone directed into the future (the present is the top of the cone). This is an area of the absolute future, the so-called cone of the future. Within such a cone, the interval between any two events will always be timelike (S^2 > 0), and therefore, all events will be causally related.

There is also another cone of light, directed into the past (the present is the top of the cone). This is the realm of the absolute past. Inside the past cone, the interval is also timelike (S^2 > 0), and therefore, this cone contains all the events that could affect the event in the present.

Note that “...the light cone can be defined as the set of all points for which the interval separating them from the given event (the top of the light cone) is light-like (that is, equal to zero, isotropic interval).

...in both special and general relativity, the concept of a light cone... makes sense for spaces of 4-velocities and 4-momenta of bodies taken in a locally Lorentzian reference frame.

The 4-speed or 4-momentum of a massive body (having a positive mass) will always lie strictly inside the cone of the future. (My note: that is, all events in our Universe will lie inside the cone of the future, since the Universe consists of massive objects (elementary particles, nuclei, atoms, planets, stars, black holes, galaxies, etc.).

From the point of view of the theory of relativity, all rays lying strictly inside the cone of the future are “equal” and “equally distant” (more precisely, infinitely distant) from the surface of the light cone. Therefore, it is impossible to accelerate a massive body to the speed of light, no matter how much and in which direction it is pushed; this phenomenon is also called light barrier.

Massless particles, on the other hand, have 4-momenta lying on the light cone itself (its surface). The concept of 4-speed for such particles is defined only up to multiplication by a positive number (its “length” is equal to 0)…” [3]. Directions in Minkowski space along which the interval is zero (S^2 = 0) are called isotropic, and light always propagates along them.

1. Parshin D. A., Zegrya G. G. Special theory of relativity and an introduction to general relativity (2016). Physics STR. Lecture 18: Interval. Minkowski geometry... Light cone. P. 10 - 11. http://www.decoder.ru/media/file/0/1243.pdf.
2. An Example Of A Light Cone, The Three-dimensional Surface - Three Dimensional Light Cone. Pngkey (Largest Archive Of Transparent PNG). https://www.pngkey.com/maxpic/u2r5a9t4t4r5t4u2/
3. Light cone. Wikipedia. https://en.wikipedia.org/wiki/Light_cone